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PLANNING AND SCHEDULING LESSONS LEARNED STUDY

EXECUTIVE SUMMARY

Final Version

Prepared for

Mission Operations and Data Systems Directorate
Goddard Space Flight Center

Prepared by

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1.0 BACKGROUND

Several factors are combining within the Mission Operations and Data Systems Directorate (MO&DSD) to focus increased attention on mission planning and scheduling issues. First, a trend exists toward increased institutionalization of flight operations support functions, embodied in requirements on the Customer Data and Operations System to support a variety of missions with a common infrastructure of services. Second, efforts are now underway to define the space and ground elements of the Advanced Space Network, whose capabilities will be critical to mission planning and scheduling. Finally, concerns have been expressed that the capabilities of the Hubble Space Telescope's (HST) planning and scheduling system may be limiting factors in the overall productivity of the observatory. Considering the similarities of future GSFC missions to HST, and the potential value of every observation they could support, there is strong impetus to assure that future planning and scheduling systems are capable of enabling each mission to operate at its full potential.

The perceived importance of planning and scheduling within MO&DSD is reflected in a number of recent and current initiatives. In April of 1989, MO&DSD presented the results of a planning and scheduling workshop to identify key recommendations to MO&DSD management. The formation of a Network Users' Group is being considered to assist with the definition of requirements on the Advanced Space Network. A study is currently ongoing to extract lessons learned from the development of the HST planning and scheduling system. Several organizations, including MO&DSD's Data Systems Technology Division, are conducting research and development projects directed at more effective planning and scheduling systems. And MO&DSD has sponsored this study to capitalize on lessons learned from individuals who have been involved in the specification, development, or operation of a variety of mission and institutional planning and scheduling systems.

One of the major lessons learned is that the end-to-end planning and scheduling process has been highly fragmented, reflecting the fragmented manner in which the elements of the end-to-end system have been developed. The impact of this fragmentation on mission productivity depends upon certain mission characteristics identified in this study. What this study conveys, however, is that MO&DSD has the opportunity to apply a considerable body of institutional expertise and system capabilities to the improvement of existing and planned systems, with considerable potential benefits to mission productivity. Drawing upon the views of 32 persons representing the experience gained from 8 missions and 5 institutional systems, this study provides MO&DSD with specific recommendations for action to enhance mission planning and scheduling.

2.0 OBJECTIVES AND ORGANIZATION

This study had three specific objectives: 1) to identify planning and scheduling "lessons learned", 2) to identify and analyze the characteristics that predispose certain missions to difficulties in planning and scheduling their operations, and 3) to formulate recommendations for action. Key recommendations are summarized in Section 3, followed by a discussion of mission characteristics in Section 4, and a description of the study approach in Section 5. Attachments A through E include the interview materials used, summary tables of lessons learned, list of reference documents, list of acronyms, and detailed descriptions of mission characteristics.

3.0 RECOMMENDATIONS

The following recommendations are directed at improving the process by which planning and scheduling systems are developed within Code 500. The relationships of these recommendations to detailed lessons learned are included in the final presentation given to MO&DSD division-level representatives on June 19, 1990.

3.1 Develop end-to-end planning and scheduling operations concepts by mission class and ensure their consideration in system life cycle documentation.

Background

The persons we interviewed consistently expressed that operational implications must be considered early in the mission life cycle, when fundamental decisions are made concerning the spacecraft design and mission operations concept. Often, the System Instrumentation Requirements Document (SIRD) is developed before the Mission Operations Concept Document, and therefore does not adequately address operationally based requirements. In several cases, detailed analysis of operational factors might have avoided subsequent major planning and scheduling problems, such as the inability of the NCC to support the type of cross support required by the HST.

Detailed Recommendation

The recommendation to develop classes of mission operations concepts is intended serve two major purposes: 1) enable MO&DSD institutional services to better address the diversity of needs among user missions, and 2) provide missions with a standard framework for an operations concept that will encourage a realistic exploration of operational concepts and implications during Phase A. The standard framework should accommodate distinct classes of operations concepts associated with different types of missions, e.g., highly preplanned versus highly interactive. Further, we recommend developing guidelines for other system specification documents, such as requirements specifications and interface control documents, and requiring that they be traceable to and consistent with the mission operations concept.

3.2 Create an organizational infrastructure at the Code 500 level, supported by a Directorate-level steering committee that includes project representation, responsible for systems engineering of end-to-end planning and scheduling systems.

Background

Another consistent lesson learned from the study was that planning and scheduling systems are developed in disjoint pieces, with inadequate coordination across the end-to-end system. System fragmentation is evident, for example, at the PASS/SOGS interface for HST and at the POCC/MPT mission interfaces, where excessive verbal communication and iteration are required to compensate for system engineering deficiencies. This fragmenation, which transcends not only divisions within MO&DSD, but also the divisions between MO&DSD, flight projects, and users, reflects a lack of technical coordination at a sufficiently high level in the organization.

Detailed Recommendation

We recommend that MO&DSD institute an active planning and scheduling system engineering function at the directorate level, including a technical committee representing all of the divisions, the Advanced Missions Analysis Office, and each project in the Flight Projects Directorate. The role of the planning and scheduling steering committee is to analyze and coordinate technical decisions that transcend individual divisions within MO&DSD. The steering committee would ensure, for example, that systems are specified and developed within the framework of an end-to-end information flow analysis, that systems are capable of supporting end-to-end and operational testing, and that users evaluate operational concepts, functionality, and man-machine interfaces. The steering committee would also support interactions with other organizations, e.g., the Flight Projects Directorate, concerning the planning and scheduling implications of high-level decisions, e.g., spacecraft design and operations concept. Finally, the steering committee could oversee the development of a strategy for achieving integration of the MO&DSD planning and scheduling elements, possibly including the development of applicable standards and common services.

3.3 Develop and refine mission modeling capabilities to assess impacts of early mission design decisions on planning and scheduling.

Background

An objective of this study was to explore the relationship of planning and scheduling lessons learned to mission characteristics, to determine whether certain types of missions are inherently predisposed to planning and scheduling difficulties. We found that mission characteristics which are related to the design of the spacecraft and the mission operations concept, such as whether observations must be conducted in real time, can exacerbate planning and scheduling. Several persons we interviewed offered that flight projects fail to adequately consider the operational impacts of their fundamental decisions regarding the design of the mission. One reason for this is that discrepancies can exist between a flight project and MO&DSD regarding the expected availabilities and capabilities of institutional resources, such as TDRSS. Another reason may be the difficulty of adequately capturing and analyzing dynamic relationships using traditional methods for specifying operations concepts, e.g., textual narrative and block diagrams.

Detailed Recommendation

The third recommendation is to develop and refine mission operations modeling tools to assess impacts of early mission design decisions on planning and scheduling, particularly requirements for such institutional resources as space-to-ground communications. These tools would facilitate the analysis of dynamic aspects of the mission concept which strain the capabilities of conventional requirements specification and analysis methods. In addition, the tools would help to reveal discrepancies regarding expected availabilities and capabilities of institutional resources.

To be effective early in the life cycle, the tools would need to function despite incomplete or uncertain data about the mission design. For example, the tools might be capable of processing whatever level of spacecraft design and operations concept information is available, and infer from it whatever operational characteristics can be inferred, at any point in the evolution of the mission concept. As more information became available, or as design alternatives are proposed, the tool suite would be capable of providing additional information regarding operational impacts. These impacts would then be used to support the decision making process. The tool suite might support consistency and traceability between the Operations Concept Document and subsequent specifications by handling multiple levels of related specifications, e.g., functional responsibilities and interface descriptions.

3.4 Emphasize operational flexibility in the development of the Advanced Space Network, other institutional resources, external (e.g., project) capabilities and resources, operational software and support tools.

Background

Most of the planning and scheduling systems we studied are designed to support a single operations concept which specifies *the* sequence in which plans and schedules are to be produced. Difficulties arise when some unanticipated event forces a deviation from the nominal sequence, such as a change to the TDRSS schedule, detection of a detailed conflict, occurrence of an on-board anomaly, or identification of a scientific opportunity. Most planning and scheduling systems are able to respond to such out-of-sequence events only through manual iteration, often requiring extensive and time-consuming verbal interactions. Unfortunately, unanticipated events are the norm rather than the exception, and often correspond to critical situations when iteration consumes valuable time. The result may be reduced communications coverage and mission productivity, particularly for the lower priority missions.

Flexibility is especially significant to institutional resources, such as space-to-ground communications. A prime example of institutional inflexibility is the fixed timeline established by the Network Control Center for requesting and scheduling TDRSS services. Because it supports multiple missions with varying needs, the Space Network needs to be more flexible to accommodate a greater variety of operations concepts, and to improve responsiveness to rescheduling situations. As MO&DSD embarks on the development of the next-generation Advanced Space Network, it is imperative to incorporate the considerable experience that has been gained by users of the current systems, particularly as this experience bears on requirements for operational flexibility.

Detailed Recommendation

The fourth recommendation is to emphasize operational flexibility in the development of the Advanced Space Network, other institutional resources, and mission operations software and tools. This flexibility, which is a function of the designs of both ATDRSS and the ground system, would include such capabilities as service-level request dispositions, extensible contacts, and flexible timelines for scheduling the use of ATDRSS services. Flexibility at the Space Network interface could also be improved greatly by partitioning TDRSS resources into secure and non-secure components, reducing impediments to the free exchange of planning and scheduling information among unclassified missions and the NCC. Other institutional resources, such as NASCOM and Flight Dynamics Facility, as well as mission planning, scheduling, and command management software should be capable of supporting nominal and non-nominal sequences of planning and scheduling activities. By supporting greater flexibility through a new generation of operations concepts (see Recommendation No. 1), rescheduling problems will be greatly alleviated.

4.0 MISSION CHARACTERISTICS

As mentioned in Section 3.3, we studied the relationship of mission characteristics (i.e., characteristics external to the design of the planning and scheduling system) to planning and scheduling lessons learned, to determine whether certain types of missions are predisposed toward difficulties. Our general finding was that the lessons learned are generally applicable to all mission types, but that a mission's sensitivity to the capabilities of its end-to-end planning and scheduling system depends upon certain characteristics. These characteristics include the inherent complexity of the planning and scheduling problem, the amount of time available for its solution, the accessibility of information required, and the dependency on the space-to-ground communications schedule. Detailed contributors to each of these characteristics are discussed in Attachment E. These characteristics depend on the spacecraft design and mission operations concept, underscoring the need to consider the operational implications of mission design decisions.

5.0 STUDY APPROACH

The general approach used to conduct this study involved three major steps:

1) Develop Framework for Interviews - the framework consisted of a set of generic planning and scheduling physical, logical and process models, which were used to facilitate communications with the interviewees. In retrospect, the models were initially useful for formulating an inquiry into planning and scheduling, but were not needed for communications purposes.

2) Collect Information - Although our primary source of information for this study was the interviews we conducted, we reviewed selected documents in preparation. Our interviews included 32 individuals representing 8 missions, 5 institutional facilities, and job descriptions including scientist, engineer, manager, and operator. An important element of the approach was to validate our interview reports with the interviewees before proceeding with the analysis. We then conducted a second validation with the interviewees after deriving lessons learned to ensure that our analysis of the results was representative of their collective experiences. We found the interviewees to be generally anxious to cooperate, candid in their responses, and generous with their time. The interview materials we used are included as Attachment A.

3) Synthesize Lessons Learned - Based on the interviews, we extracted individual lessons learned, such as "The NCC algorithm for the use of time tolerances takes earliest possible time, rather than most desirable time, and therefore discourages use of the capability by higher priority users." At the same time, we grouped the lessons learned using such summary statements as "Needs to be Operationally Viable", and grouped the summary statements into such categories as "Software Design" and "Human Factors Engineering". This hierarchical organization was required to manage the large volume of data that we analyzed. We then analyzed each detailed and summary lesson learned against the missions and institutional systems to determine the extent of its applicability. For example, the lesson learned about the use of time tolerances was relayed by Network Control Center personnel, and is most applicable to high priority missions, such as HST. We identified any particularly noteworthy lessons learned in this process as potential "tall poles", indicated in the summary tables by italics. Finally, we formulated detailed recommendations from the lessons learned, which are included in the June 19, 1990 presentation package. The higher-level recommendations in section 3 of this report and in the presentation were abstracted from these detailed recommendations.

In retrospect, much of our analysis and intermediate products contributed mainly to our understanding; the results seem to be most effectively communicated through the recommendations.

ATTACHMENT A

Interview Materials

The following instrument is intended to guide a discussion that will result in a) a fairly detailed description of the mission planning and scheduling process for the selected missions, and b) an evaluation of what's "good and bad" about the way things have been done/are being done/might be done that will provide "lessons learned". The key questions will be distilled from this instrument and made available to the interviewees. Note that there are sections that can/would excluded for certain interviewees.

Planning & Scheduling Interview

Mission:______________________ Date:__________

Interviewee: Name:______________________

Position:______________________

Length of Time in Position:______________________

Location:______________________

Interviewer(s):______________________

Part A: Mission Definition

Section I: Overall Mission

1. Using the Functional Model as a basis, describe the process for mission planning and scheduling by identifying:

   - any steps that are not applicable to your mission or steps that are missing from the model
   - the details for each step in the process
   - the frequency, volume, and average time involved for each iteration within a step
   - who (role and primary person's name) is responsible for initiating and completing each step
   - the products and their content outline for each step
   - whom those products go to
   - when on a timeline the steps occur, and when on the timeline the various products have to be handed off
   - what facility(ies) each those steps occur in

2. Using the Facility Model as a basis, describe the overall end-to-end system (including ramifications of a particular operations concept for science) by identifying:

   - which facilities and flows are valid for your mission
   - any facilities that are missing from the model
   - any flows that are missing from the model
   - any mission-specific attributes of the facility
   - any dependencies of planning and scheduling on previously acquired science data

3. Besides TDRS, are these the other institutional resources that have to be scheduled?
   - CMS
   - Data Capture Facility
   - DOCS to AP load

4. The following are characteristics or conditions that describe parts of the end-to-end facility model. In some cases, you can simply indicate which

apply to this mission. In other cases, a description or judgement is necessary.

a. Phenomena
- observations must occur at precise times
- observations are contingent on one another
- observations are not predictable and require interaction with users to be obtained

b. Instruments
- [earth | space] pointing
- [stable | dynamic] pointing
- environmentally compatible with one another and with the spacecraft
- [low | high] level of autonomy
- have postional constraints
- have different priorities

c. Spacecraft
- resource rich in terms of:
  power
  onboard memory
  onboard storage (tape recorders)
  downlink bandwidth
- operational conflicts with instruments
- [low | high] level of autonomy
- positional constraints
- priority of TDRS contact
- mode of onboard command handling
- sophistication of onboard data system

d. Space Network
- nature of interface
  use of generic scheduling
  [rare | frequent] non-availability
  verbal vs. electronic
  [low | high] degree of iteration
- emergency DPS
- timing of requests/schedules/denials

e. POCC
- fault-tolerant system
- dedicated vs. shared
- level of simulator fidelity
- [low | high] level of mission/science conflict resolution
- number of operators
- dedicated operators
- where located

f. Command Management Facility
- shared vs. dedicated
- amount of time required to produce loads
- nature of interfaces with other facilities

medium
frequency and volume
degree of iteration

- number of users
- where located
- time to load software from DOCS to AP
- time before TDRS contact for loading AP fixed or variable

g. Science Operations Center
- [low | high] level of instrument conflict resolution
- highly volatile vs. static environment
- number of people involved
- where located

5.. What tools or aids are currently available to support the planning and scheduling functions for the mission?

6.. What additional tools or other support would be helpful?

7. How long and what type of effort was included in determining the specific collection of instruments for this mission?

8. How many contractors are involved in this mission:
   - for the ground system?
   - for the spacecraft?

9. Is the priority of the mission fixed or is it relative to what else is "happening"?

10. How are conflicts between missions resolved at the Directorate level?

Section II: Subsets of the Mission Planning and Scheduling

1. Using the Functional Model of the Planning and Scheduling process, identify which step(s) you participate in.

2. For each step:
   - What are the activities (be as specific as possible) that are performed?
   - How much time do you spend on these activities?
   - What is the timeline for these activities to be accomplished?
   - What are the products and what form are they in? (e.g., textual plan on paper, command load in machine-readable form)
   - To whom and to which facility do the products go (for review, approval, delivery)?
   - How long does it typically take to create the product(s)?
   - Is the process typically very iterative?
   - How long might an iteration take? (e.g., number of days, hours, weeks)
     How frequently do the iterations occur?
     When in the timeline are they most likely to occur?
   - What is the frequency and impact of rescheduling?

How is rescheduling different from initial scheduling?

3. How many people are involved in the process and how do you organize the process?

4. What, if any, are the current software aids available for your use?
   - How effective have they been?
   - At which specific points in the P&S are they used?

5. What services and/or tools do you think would be helpful in mission planning?

Section III: Role-Specific Questions

Project Scientist

1. How do you resolve conflicts between instrument scheduling needs?

2. How would you describe the instrument set in terms of:
   - numbers of instruments
   - flexibility of instruments
   - compatibility of instruments (e.g., environmentally, purpose)
   - level of autonomy
   - priorities amongst them
   - techniques used to maximize resources (e.g., data compression)
   - positional constraints

3. How would you describe the spacecraft characteristics in terms of:
   - pointing
     stable vs. dynamic
     earth vs. space
   - resources: rich vs. poor
     power
     onboard memory
     downlink bandwidth
     storage available (e.g., tape recorder)
   - conflicts with instrument requirements
   - positional contraints
   - priority for TDRS contact
   - level of sophistication of onboard data system
     autonomy
     method of onboard command handling

4. Describe the nature of user requests in terms of:
   - how many users
   - volume of requests
   - degree of flexibility possible/desired
     absolutes vs. ranges
     resource requirements
     temporal constraints
     user-defined priority
     repitition
     temporal preference

environmental requirements
dependent on execution of other commands vs. independent

Data Systems Manager/Command Management Systems Manager,et. al. [POCC]

1. Does the receipt of data from the FDF have any potential impact on the scheduling done in the POCC?

2. How far in advance do you send schedule requests to the NCC?

3. What length of time does the schedule request cover?

4. How long does it take to get the schedule/denial back?

5. What is the percentage of requests that are:
   - accommodated on the first round?
   - successfully rescheduled?
   - not accommodated?

6. If there is a denial of schedule request, where does the rescheduling start from?

7. What are the major factors in rescheduling?

8. Does rescheduling have a similar or different process?

Institutional Facilities

NCC

1. How many users do you service?

2. How are the scheduling requests handled?
   - Is there a dedicated person per mission?
   - Is there a prioritization scheme for missions?
   - Do all the missions send their schedule requests once per window, or are there iterations within a given window request?
   - Do all the missions interact with the NCC in the same way?

3. What, if any, are the current software aids available for your use?
   - How effective have they been?
   - At which specific points in the P&S are they used?

4. What services and/or tools do you think are required to aid you in mission planning?

5. What percentage of the requests you receive are you able to comply with on the first go-round?
   - About how many iterations might be expected?
   - Are there certain kinds of requests that are more likely to be denied or rescheduled?

6. What is the nature of the interface(s) for planning and scheduling?
   - How much voice, paper, electronic communication is typical?
   - How much time is spent in the rescheduling process?
   - Is there anything about the nature of the requests you receive that could be changed to minimize the iterations?

7. How will ATDRS effect the way planning and scheduling are conducted?

8. How will scheduling be affected by the use of the STGT?
   - What will differ about the interface?

9. What are the biggest problems you face with respect to fulfilling schedule requests?

10. What are the reasons and approximate percentages for inability to meet requests due to:
    - equipment failure
    - security interference
    - internal scheduling problems
    - too short a turnaround time for request
    - too inflexible a request

CMS

1. How many customers are supported?

2. Are there great differences in the requirements for different missions?

3. What is the nature of the interface with the:
   - POCC
   - different missions
   - FDF

4. What tools or aids are currently available to support the planning and scheduling functions for the missions?

5. What additional tools or other support would be helpful?

FDF

1. How many customers are supported?

2. Are there great differences in the requirements for different missions?

3. What is the nature of the interface with the:
   - POCC
   - different missions

Part B: Lessons Learned

1. What are some of the "negative" lessons learned thus far? For each lesson learned, please consider the following:
   - what mission characteristics do you think the lesson has as its source?
   - what, if any, alternatives were considered or attempted to address the situation?
   - what is the real impact of this problem to the overall P&S process? (on a scale perhaps)
   - is there a recommendation you can make to alleviate this problem?
   - what would be the impact of this solution to the overall P&S process?

2. What aspects of this mission do you think are "positive" lessons learned?

ATTACHMENT B

Summary Tables of Lessons Learned

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I. Accurate and Adequate Knowledge of Current Institutional Support

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
A. *Capabilities and constraints of TDRSS not clearly understood*	*H*	*H*	*M-H*	*H*	*M-H*	*M-H*	*M*		*H*			*H*
– Realistic level of potential coverage not made known – much more real time expected than possible	H	H	M-H	H	H	M	M					H
– Documentation doesn't identify all limitations	M	M-H		H								H
– Documentation includes non-existent capabilities				H								M-H
– Users (and user software) shouldn't need to know low-level details (e.g., scheduling for gap between TDRS-E and TDRS-W)	H	H		H		H						H
– Scheduling success percentage is based on time available, not 100% of the time			M-H		M-H							
– Capacity planning studies are generally available only to HQ, not missions		M-H										M
– Having secured and non-secured missions and STS sharing scheduling resources makes scheduling and fault isolation very difficult	H			H	H	H	H		H			H
B. Interfacing to developing systems impacts operations	H	L		M	H		M-H					M-H
– No formal channels exist for apprising users of new system developments							M-H			M		M-H
– Hard to design, build to, or interface with a system where requirements and capabilities are changing (e.g., TDRSS, CMS)	H			M	H		M-H					

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II. Distribution of Functional Responsibility, Authority, and Information

LESSONS LEARNED

SUMMARY STATEMENT/DETAILS	MISSIONS COBE	ERBS	EUVE	HST	LSAT	SME	SMM	SYSTEMS CMF	FDF	MSOC	NSCM	NCC
A. Knowledge/authority exists outside domain of functional responsibility	M-H	M	M	H	H		L-M	M-H	M-H	H		H
– Schedule conflict resolution at NCC requires input from multiple missions personnel	M			H	H							M-H
– Flight Operations Team's authorization is required prior to MPT transmission of schedule requests to NCC	M-H	M						M-H		H		H
– Project (POCC or instrument team) expertise is required to resolve conflicts in and/or verify command loads	H							H		M-H		
– Complete knowledge of scheduling restrictions is not available to mission ops personnel	M-H		M	H	H		L-M		M-H			H
B. People and/or software have responsibility without the necessary information readily available	M	M-H		H	H		M-H	M-H	H			M-H
– Valid schedule generation requires use of UAVs, which are not accepted electronically by the NCC	M	H							H			M
– Interfacing software does not always have cognizance of all required data (e.g., PASS command loader not being cognizant of time restrictions can lead to memory overrun)	M			H				H				
– TDRSS users are responsible for creating schedule requests, but do not have access to all information (e.g.,available times) needed to do so	M-H	M		H	H	H						

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II. Distribution of Functional Responsibility, Authority, and Information (continued)

LESSONS LEARNED

SUMMARY STATEMENT/DETAILS	MISSIONS: COBE	ERBS	EUVE	HST	LSAT	SME	SMM	SYSTEMS: CMF	FDF	MSOC	NSCM	NCC
– GCMRs require POCC users to supply MA return link information, which they must acquire from the NCC	M											
– POCC has responsibility for command loads (i.e., number and locations) but does not control load processing	H	H					M-H	M				
– NCC must verbally communicate with POCCs to obtain knowledge of mission requirements it needs to resolve conflicts	M	M										M-H
C. The greater the physical distribution of human beings, the greater the effects on timeliness and effectiveness of conflict resolution	H			H		H	H	H				
– Being physically close allowed a wide scope of knowledge to be shared more easily and provided for face-to-face P&S	H			H		H	H	H				
– The time required for conflict resolution increases with numbers of people and/or distances between people	H			H		H		H				H
– Having knowledge of S/C attitude in the POCC was helpful				H								

II. Distribution of Functional Responsibility, Authority, and Information (continued)

LESSONS LEARNED

SUMMARY STATEMENT/DETAILS	MISSIONS							SYSTEMS				
	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
D. Redundant functionality is not always implemented consistently and leads to data integrity problems	M		H	H								H
– Algorithms (e.g., modelling HGAs position star guide selection) provide different results that create errors in and delay the scheduling process				H								
– Implementations for science room and MOR for the same mission should be consistent (e.g., STOL for COBE, constraint checking for EUVE)	M		H									
– There are different definitions and treatment of cross-support in TDRSS (tracking only) vs. NCC (tracking, plus other services)				H								H
E. Duplication of data entry (electronic and/or manual) is wasteful, time consuming, and can increase chances for error	H	M	M	H				M		H		
– Data entry of information previously captured on paper forms creates delays, increases chances of error (e.g., MSOCC MPT, HST RPSS)	H	M	M-H	H				M		H		
– Data from FDF computer printouts is manually entered into mission systems by FOT members (e.g., PSATs for COBE)	H	H	M					M				

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II. Distribution of Functional Responsibility, Authority, and Information (continued)

LESSONS LEARNED

SUMMARY STATEMENT/DETAILS	MISSIONS: COBE	ERBS	EUVE	HST	LSAT	SME	SMM	SYSTEMS: CMF	FDF	MSOC	NSCM	NCC
F. Volume and presentation of data impedes efficient analysis	M-H			H				H	H			H
– Use of tapes (e.g., CMS, FDF) makes access and transaction with specific data more difficult and time consuming	M-H							H				
– Volume of data presented (e.g.,NCC screen for conflict resolution, PASS output to SOGS) is over whelming				H				H				H
G. Non-integration and redundancy of data affects reliability	M			H		H				H		H
– Three copies of configuration codes must be maintained at separate locations (POCC, MPT, NCC), causing confusion over management responsibilities and occasional inconsistencies										H		M-H
– Separate mission/instrument databases cause errors	M-H			H		H						M-H
– Mission schedule and request databases may not be synchronized with NCC database	L-M									H		H

III. Software Design

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
A. *Redundant functionality needs to be implemented consistently*	*M*		*M*	*H*								*H*
– Algorithms (e.g., modelling HGA's guide star selection position) provide different results that slow down the scheduling process				H								
– Definition of cross-support differed in TDRSS and NCC				H								H
– Implementations for a given mission should provide consistent capabilities (e.g., STOL for COBE, constraint check for EUVE)	M		M	H								
B. *Needs to be operationally flexible*	*M-H*		*H*	*H*	*H*	*H*		*H*				*H*
– Software should not reflect one single operations concept/scenario (e.g., daily basis only, continuous real-time, 1 safe mode required by CMS)	M-H			H		H		H				H
– Use variable data at latest possible time in processing (e.g., RT–>UT, ephemerides)				H		H		H				
– Allow for iterations (e.g., NCC active schedule, HST SMSs, EUVE, TOOs)			H	H	H							H
– Changes (e.g., how I&Q channels are used, SSA antenna selection) should not require rescheduling	H			M								

III. Software Design (continued)

LESSONS LEARNED | MISSIONS | SYSTEMS

SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
– Constraint analysis software should allow for new constraints (e.g., WFPIC – requires patch)				H	H			H				H
C. ***Needs to be operationally viable***	*H*	*H*	*H*	*H*	*H*	*H*	*H*	*H*				*H*
– NCC algorithm for use of time tolerances takes earliest possible, rather than most desirable, time and, therefore, discourages use of the capability by higher priority users												H
– Required rule bases (e.g., TDRS constraints, memory constraints) are frequently not available to the software where it is needed	H			H				H				
– Algorithms for conflict detection should consider relationships among three or more attributes				H	H							
– Users should not have to keep track of what data they have provided– the software should (e.g., NCC SAR)				H						H		H
– Codify as much conflict resolution criteria as possible	H	H		H	H	H	H	H				
– Codify as much constraint checking as possible (e.g., TDRS really in line of sight, tracking configurations valid) to produce supportable schedule requests	H	H	H	H	H	H	H	H				H

III. Software Design (continued)

LESSONS LEARNED | **MISSIONS** | **SYSTEMS**

SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
– An entire request shouldn't be denied because <u>one</u> of the services is in conflict	H	H		H								H
– Requests need to be resubmitted even for the lowest level change (e.g., changes in I&Q channels)	H			H								
– Requests have to be completely resubmitted if the request is rejected, rather than just allowing the necessary edits to be made and resubmitted	H									H		H
– Having non-mission specific functions developed by a mission (e.g., HST attitude determination) may not be advantageous				H				M-H				
– Priority scheme of the 50's is not appropriate tooday; software could support changeable priorities[1]												
– It is not realistic to submit our schedule requests during the Forecast Period; we don't have good enough data[1]												

[1]Submitted by STS

LESSONS LEARNED

SUMMARY STATEMENT/DETAILS	MISSIONS							SYSTEMS				
	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
A. Should support flexibility in operations	H				H		H	H	H			
– Having multiple files of command loads or schedules available at the same time to allow comparative evaluation would be helpful	M-H							H				
– A "what if" capability (e.g., NPAS) for generation of versions of command loads or schedules to allow comparisons would be helpful	H							H				H
– TDRSS could be scheduled in advance to some extent (e.g., to accommodate regular tape recorder dumps)	M-H				H							H
B. People are performing tasks that would be more easily and better performed by automation	H	H	M		H	H	H		H			H
– Requesting basically repetitive supports such as routine tape recorder dumps could easily be supported by an automated tool	M	H	M		H		H		H	H		H
– Selecting usable TDRSS contacts from a hard copy printout could be supported by an automated tool	H	H				H			H			

IV. Automated Support Tools (continued)

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
C. *Lack of flexibility in request generation leads to repetitive request generation and iterative transmission*	*H*			*H*								*H*
– Tolerances are only provided at the event level				H								H
– Should not have to specify which antenna to use (25% conflicts)	H			H								H
– Should not have to resubmit requests if item changed (e.g., I&Q channel, time) doesn't change description of support	H			H								H
D. Needs to be appropriate to system and user requirements	M-H			M-H		H		M-H	H	H		H
– Sizing of MPT is inadequate to support missions	M			M-H		H				H		M-H
– Users should not have to know which codes to select from a screen	H			M-H		H						
– Interface (both device and screen) affect ease of use (e.g., light pen on MPT not efficient, graphic display of COBE, character display on NCC)	H			M-H		H				H		H
– Information is frequently provided in an unwieldly volume and presentation	L-M			H				M-H	H			H

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V. Hardware

LESSONS LEARNED — MISSIONS — SYSTEMS

SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
A. *There are insufficient resources for test and integration support*	*M-H*			*H*			*H*					
– Testing the NCC scheduling interface is difficult because it requires use of real scheduling requests and the real timeline				H							H	
– Contention for shared resources resulted from new mission testing during orbiting spacecraft operations (HST and GRO affected COBE, ERBS)	M-H						H			M		
– NCC development system does not have dual computer configuration so realistic testing is not easily supported	M			H								
B. Concern about adequate resources	H			H			H	H		M-H		
– Contention for shared resources requires verbal communication on scheduling prior to access to resource (e.g., CMS P&S, and attitude control/ sensor calibration)	H			H			H	H				
– Resources should never be single-user	H							H				
– Dedicated mission system components are highly desirable (e.g., for command management)	H						H					
– Should be more realistic sizing and loading requirements	M			H								

V. Hardware (continued)

LESSONS LEARNED	MISSIONS							SYSTEMS					
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
C. Security issues increase the impact on hardware requirements	M-H			M								
– Resources being allocated to support security are decreasing resources available for original purpose	M-H			M								
D. Use of incompatible hardware increases difficulties in interfacing systems	M-H			M-H								
– Incompatible hardware resulted in development of many gateways, protocol inconsistencies, which affected how well and quickly things got done	M-H			M-H								
E. Hardware acquisition cycle may result in procurement of inappropriate hardware because requirements are not well understood	M-H											
– E.g., EAW is overkill – has to be made into a dedicated terminal like what it replaced; computer "cluster" costs months trying to implement	M-H											

VI. Human Factors Engineering

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
A. *Developing sense of team is very important*	*H*	*H*		*H*	*H*	*H*	*H*	*H*			*H*	*H*
– Bringing the operational people on-board early on really helps make team work	H	H		H	H	H	H	H			H	H
– Boundaries – for responsibility and ability to accomplish task needs to be clearly identified and agreed to (e.g., CMS vs. POCC for command management)	H	H		H		H	H	H			H	
B. Valid reasons should exist to require humans in the loop	H	H		H	H	H	H	H	H	H		H
– Evaluate technical feasibility		H		H	H	H	H					
– Provide judgment in conflict resolution (management)	H	H		H	H	H	H	H		H		H
– The purpose of voice communications should serve to supplement, not replace or supercede, automated electronic communications	H			H	H		H	M-H	H	H		H
C. Displayed messages should provide clear and sufficient information	M-H			M	M-H		M-H					
– "Negative acquistion" message from NCC doesn't let POCC know its spacecraft is OK, which is not acceptable; error messages from PASS-system or source data problem	M-H				M-H							

VI. Human Factors Engineering (continued)

LESSONS LEARNED — MISSIONS — SYSTEMS

SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
– Schedule rejection messages displayed at POCC must be followed up by verbal communication to resolve conflict	M-H			M	M-H		M-H					H
D. Provide ease of use rather than flexibility in user interface						H		H		H		H
– User interface needs to be appropriate for skill level of user (e.g., CMS operator vs. FOT member doing CM, dedicated MPT operator)						H		H		H		H
– Efforts for graphical interface were put on hold due to STGT funding priority												
E. All affected users should be involved in software development for operational suitability	*H*	*H*	*H*	*H*								*H*
– Too little operational involvement (e.g., NCC, COBE) too much (science) involvement negatively impacts operational suitability (e.g., COBE, HST)	H	L	H	H								H
F. Communications involving human beings is sometimes a result of not having an electronic interface that truly supports the communication requirements	*M*						*M*	*M*	*M-H*	M-H		*M*
– System readiness must be verified before transmitting data (e.g.,schedule/requests)	M						M	M	M-H	M-H		M

VI. Human Factors Engineering (continued)

LESSONS LEARNED | MISSIONS | SYSTEMS

SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
G. Staff skills and performance capability are often overestimated	M			H				M-H				H
– Staff can be overextended (e.g., 1-2 people needed to run mission scheduler and command leader, 2 people to do everything else in PASS)				H								M-H
– Changing location of a function may result in relatively unskilled users (e.g., CMS opeator in FOT)								M-H				
– System operators need to be adequately trained				H				H				H
– Support from off-shift workers not as reliable as from regular shift	M											

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VII. Communications

LESSONS LEARNED

SUMMARY STATEMENT/DETAILS	MISSIONS: COBE	ERBS	EUVE	HST	LSAT	SME	SMM	SYSTEMS: CMF	FDF	MSOC	NSCM	NCC
A. Operational electronic interfaces still requires human intervention	M-H		M-H	M	M		H	M-H	M-H	M-H	H	M
– MPT/NCC, MPT/CMF, NCC/POCC, POCC/CMF electronic interfaces must be coordinated verbally	M-H		M-H	M	M		H	M-H	M-H			M-H
– Data must be extracted from one system and re-entered into another	H		M-H		M			M-H	M-H			
– Reconfigurations have to be manually implemented								M-H		M-H	M	M
B. Lack of (adequate) electronic interface affects data availability	*H*	*H*	*H*		*L-M*			*H*	*H*	*H*		*M*
– Absence of electronic interface results in manual re-entry of data	H	H	H		L-M			M-H		H		
– Current interfaces make planning and scheduling aids unavailable for easy POCC usage (i.e., FDF PSATs, unless they develop software to read tapes)	H	H						H	H			
– SN Periodic Maintenance, BRTS, etc., scheduling requests and fault isolation must be verbally conveyed									M			M

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VII. Communications (continued)

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
C. Inadequate communications capabilities affects resource availability	M	M										M
– Having one NASCOM line into POCCs disallows continuous TDRSS coverage	M											
– Contention for SSA link exists; some missions have to use MA (which isn't always ideal)	M	M										M
– Some missions are looking at two HGAs to support communications requirements												M

VIII. End-to-End Systems Management

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
A. *Mission operations concepts are not detailed enough early enough*	*H*	*H*	*H*	*H*	*H*		*M-H*	H				H
– SIRD lags ops concept development				H								
– Need to address the flight and ground systems as a unit, the instrument complex as a unit, and the instruments and spacecraft as a unit	H	H	H	H			M					
– Need to be based on realistic assumptions and resource requirements	H	H	H	H	H		H	H				H
– Mission timelines are developed late in life cycle	H		H	H				H				M-H
– Only the nominal mission ops concept is considered (e.g., real-time for HST only during OV)			H	H								H
– The SIRD process does not reflect or address the issues related to the use of TDRSS												
B. *The greater the number of contractors and organizations involved, the greater the risk in development and operations*	*H*	*M-H*	*M-H*	*H*		*M*		M-H				*H*
– Large numbers of contractors and organizations frequently result in duplicated or addressed activities due to lack of clear controlling authority	H	M-H	M-H	H		M						H
– Multiple contractors result in inability to reuse software even when technically feasible due to "ownership by contractor"	H			H								H

VIII. End-to-End Systems Management (continued)

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
– Can end up isolating parts of the system from other parts (e.g., having STOMS manager isolated project elements from some Code 500 elements)	M-H			H				M-H				
– Contracts do not always cover interfaces well (e.g., SOGS/PASS)				H								M-H
C. *Insufficient early and continuing operational testing has a major impact*	*H*			*H*	*H*		*H*	*M*				*H*
– Software deficiencies and conflicts (e.g., HST conflict resolution algorithm, WSGT/NCC concepts of cross-support) are discovered late in the timeline	M-H			H								H
– Unknown constraints (e.g., unable to support parallel science) come as surprises	M-H			H								
– Identify communications interface problems	H			H	H		H	M			M	H
– Simulations frequently late (e.g., 3 weeks before launch)	H			H			H					
– TDRSS testing should be considered on the critical path												
D. Interfacing to developing systems affects operations	M			H	H		H					
– Cannot build to a changing set of requirements	M			H	H		H					

VIII. End-to-End Systems Management (continued)

LESSONS LEARNED	MISSIONS							SYSTEMS				
SUMMARY STATEMENT/DETAILS	COBE	ERBS	EUVE	HST	LSAT	SME	SMM	CMF	FDF	MSOC	NSCM	NCC
– Upgrades are not always compatible and build testing is not always performed				H	M-H		H					M
– Switches in development contractors has serious schedule impacts	H											
E. *Authority and responsibility for enforcing requirements and procedures is not always clearly known and enforced*	*H*		*H*	*H*		*H*	*H*					*H*
– Having clear-cut lines of authority and control really make a difference to resolving problems	H		H	H		H	H					H
– Sometimes there is no single point of contact (both at project and institutional ends) to resolve problems	M-H		H	H			M-H				H	
F. Documentation doesn't always convey "what's so"	M-H		H	H					M			H
– ICDs may be very accurate at low-level, but inaccurate or incomplete at the operational interface level (e.g., precise delivery requirements for NCC handled verbally)	M-H		H	H					M			H

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ATTACHMENT C

List of Reference Documents

DOCUMENT NAME	DATE	REFERENCE NO.
COBE		
Cosmic Background Explorer (Revision 1)	10/89	0001
Project: Cosmic Background Explorer (COBE) Support Instrumentation Requirements Document (Revision 2)	09/23/87	0002
Cosmic Background Explorer (COBE) "L&EO Operations: A Recap and Final Operations Report"	11/28/89	0041
FDF		
Flight Dynamics Division (FDD) Interface Control Document for Generic Data Product Formats	01/90	0052
GENERAL		
Mission Planning and Scheduling Workshop Report Mission Operations and Data Systems Directorate	04/14/89	0050
Mission Planning and Scheduling Workshop Results	04/14/89	0051
A Planning and Scheduling Lexicon	09/15/89	0054
SAIS Payload Operations Management Concept (Draft Version 3.0)	10/06/87	0019
SAIS Architecture and Interfaces	01/21/86	0020
Appendix D - Interviews on Remote Operations Section D-1 - Sample Interview Guide for Meeting on Remote Operations Issues		0022
Background Notes for MO&DSD P&S Workshop		0029

DOCUMENT NAME	DATE	REFERENCE NO.
Everything You Wanted to Know About a Payload Operations Control Center (POCC)	01/19/90	0030
Integrated Resource Scheduling in a Distributed Scheduling Environment		0031
Mission Operations Splinter Group Summary Report		0032
Mission Operations and Data Systems Directorate Space Network Overview	09/85	0059
Mission Operations Division (MOD) Long-Range Plan	04/89	0060
Code 502 Explorer Mission Studies: Slew Table/Gimbal Angle, PACOR/UCB-BCE Interface and Target of Opportunity	09/89	0061
GENERIC SCHEDULING		
Request - Oriented Scheduling Engine (ROSE) Design Review	06/88	0036
Scheduling Concepts, Architectures and Networks SCAN Demonstration Briefing	09/29/89	0037
SCAN Demonstration Handout	09/28/89	0038
Is Generic Scheduling desirable for scheduling TDRSS	12/19/89	0039
Slides: Premises, Generic Scheduling, Ideal P&S Operations, Proposed P&S Ops, Questions		0040
Status of TDRSS Generic Scheduling Prototype Draft Project Management Plan for the MSOCC Applications Resource Scheduler (MARS) Analysis Report of Results of Comparing Three Different Generic Scheduling Algorithms as Applied to TDRSS Scheduling for the 1995 Era	03/14/90	0045

DOCUMENT NAME	DATE	REFERENCE NO.
English Translation of Selected Generic Requests used in the TDRSS Generic Scheduling Prototype Discussion of Operational Issues of Implementing Generic Scheduling in the NCC		
SEAS Monthly Status Review: NCC Generic Scheduling Prototype Task 20-103	01/19/90	0064
GRO		
Gamma - Ray Observatory (GRO) Systems Operations Requirements Document (SORD) (Revision 3)	12/15/86	0003
Gamma - Ray Observatory (GRO) Support Instrumentation Requirements Document	09/06/85	0004
HST		
Ports Commanding Subsystem Overview		0005
Space Telescope Observatory Management System Independent Test and Verification Plan (Revision A)	11/84	0006
A Simulation Model of NASA's Hubble Space Telescope (HST) Ground Support Data Processing Network for Mission Scheduling		0018
Article: Will the Hubble Space Telescope Compute?	03/89	0021
Space Telescope Observatory Management System Mission Scheduling Model Final Report	03/24/89	0023
Final Report Consulting Contract for OTA Operations on the Hubble Space Telescope	12/88	0042
LANDSAT		
NASA Support Plan Land Land Satellite (Landsat) Missions	03/85	0007

DOCUMENT NAME	DATE	REFERENCE NO.
Project: Landsat-D Support Instrumentation Requirements Document (Revision 1)	03/81	0008
SME		
Mission Operations Plan for the Solar Mesosphere Explorer		0009
Solar Mesosphere Explorer Project Support Instrumentation Requirements Document	06/80	0010
Solar Mesosphere Explorer Operations Requirements Document	04/84	0062
AIAA 26th Aerospace Sciences Meeting: Lowering the Costs of Satellite Operations: Lessons Learned from the Solar Mesosphere Explorer (SME) Mission	01/11/88	0066
SMM		
Project: Solar Maximum Mission (SMM) Support Instrumentation Requirements Document		0011
Deep Space Network (DSN) Support Instrumentation Requirements Document (SIRD) for the Solar Maximum Mission (SMM) Extended Mission	04/12/88	0012
SN		
STGT Phase II Specification	12/15/87	0057
NCC Operations Overview Space Network Scheduling	03/23/89	0063
Interface Control Document Between the Network Control Center and the Mission Planning Terminals	09/84	0058

DOCUMENT NAME	DATE	REFERENCE NO.
Effects of the Second TDRSS Ground Terminal on the High-Speed Message Interface Between the NCC and the SN Users	05/16/88	0028
Network Control Center (NCC) User Planning System (UPS) Preliminary Design Review (PDR)	02/14/90	0043
Multisatellite Operations Control Center (MSOCC) Scheduling Procedures	07/88	0044
Minutes of the Third NCC/User Working Interface Group (NUWIG)	06/12/89	0048
Appendix. Space Network Augmentation	09/88	0049
Network Test and Training Facility TDRSS Orientation and System Data Flow Course 880 Textbook		0053
MPT Mission Planning Terminal	03/22/88	0055

ATTACHMENT D

List of Acronyms

ACRONYM LIST

AMAO	Advanced Missions Analysis Office
ASN	Advanced Space Network
ATDRSS	Advanced TRDSS
BFEC	Bendix Field Engineering Corp.
BRTS	Bilateration Ranging Transponder System
CM	Command Management
CMF	Command Management Facility
CMS	Command Management System
COBE	Cosmic Background Explorer
CSC	Computer Sciences Corporation
EOSAT	Earth Observing Satellite
EP	Explorer Platform
ERBS	Earth Radiation Budget Satellite
EUVE	Extreme Ultraviolet Experiment
FDF	Flight Dynamics Facility
FOT	Flight Operations Team
GCMR	Ground Configuration Message Request
HGA	High Gain Antenna
HST	Hubble Space Telescope
HQ	Headquarters
ICDs	Interface Control Document
I&Q	I Interface Channel & Q Interface Channel
JSC	Johnson Space Center
LANDSAT	Land Satellite
MA	Multiple Access
Mbs	Megabits Per Second
MMU	Mission Management Unit
MOCD	Mission Operations Concept Document
MO&DSD	Mission Operations and Data Systems Directorate
MOM	Missions Operations Manager
MOR	Mission Operations Room
MPT	Mission Planning Terminal
MSOCC	Multisatellite Operations Control Center
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NCC	Network Control Center
NOAA	National Oceanographic and Atmospheric Administration
NPAS	Network Planning and Analysis System

NSM	Network System Manager
NTO	Network Testing Office
OAO	
OV	Orbital Verification
P&S	Planning and Scheduling
PASS	POCC Applications Software Support
PASSOPS	PASS Operations
POCC	Payload Operations Control Center
PSAT	Preliminary Sight Acquisition Table
RPSS	Remote Proposal Submission System
RT	Real Time
SAR	Schedule Add Request
SIRD	Support Instrumentation Requirements Document
SME	Solar Mesosphere Explorer
SMM	Solar Maximum Mission
SN	Space Network
SNC	Space Network Control
SNUPI	Space Network User POCC Interface
SOGS	Space Operations Ground System
SORD	System Operations Requirements Document
SSA	S-band Single Access
ST	Space Telescope
STGT	Second TDRSS Ground Terminal
STS	Space Transportation System
STDN NM	Spaceflight Tracking and Data Network Network Manager
STOMS	Space Telescope Observatory Management System
STOL	
TDRS-E	Tracking and Data Relay Satellite - East
TDRS-W	Tracking and Data Relay Satellite - West
TDRSS	Tracking and Data Relay Satellite System
TOOs	Target of Opportunities
UAV	User Antenna View
U of CO	University of Colorado
UPS	User Planning System
UT	Universal Time
WF/PC	Wide Field/Planetary Camera
WSGT	White Sands Ground Terminal

ATTACHMENT E

Mission Characteristics

E.0 DETAILED MISSION CHARACTERISTICS

In general, the challenge of designing a mission planning and scheduling system is a function of the inherent complexity of the mission's planning and scheduling problem, accessbility of the knowledge needed to fomulate and solve each planning and scheduling problem, the time available for planning, scheduling, and replanning, and the mission's dependency on the space/ground communications schedule. (Although the last characteristic could be considered part of the inherent complexity of the problem, it is treated separately because of the programmatic separation of space/ground communications resources from a mission's own resources.) These characteristics are described in following section, and their interrelationships are illustrated in Figure E-1.

E.1 **Scheduling Problem Complexity** - the inherent difficulty of planning and scheduling a given mission's activities is a function of how many activities must be scheduled per time period and the degree of dependencies and constraints between the activities.

E.1.1 Degree of dependencies and constraints - the degree of dependencies and constraints between activities affects the number of possible ways of scheduling those activities, which in turn affects the number of operations required to determine a solution.

E.1.1.1 Orbit/attitude/target relationship - the interplay of the relative motions of target and spacrcraft drives pointing requirements. Pointing is constrained by requirements for solar flux on power arrays, thermal state of the spacecraft and instruments, constraints on the rate at which the spacecraft can be slewed, constraints on the spaces at which instruments can be pointed while slewing, slewing power consumption, and conservation of momentum principles.

E.1.1.2 Spacecraft resource constraints - power, communications, and thermal rejection constraints are partly a function of the design of the spacecraft and instruments. The provision of minimal capacities constrains the planning and scheduling problem.

E.1.1.3 Space/ground communications resource constraints - space/ground communications resource constraints are partly a function of the Space Network's capacity and partly a function of the mission's priority.

E.1.1.4 Correlative/Corroborative Science - requirements for joint observations and experiments between instruments add dependencies to the planning and scheduling problem.

E.1.2 Activities per time period - the number of different activities to be scheduled in a given period of time affects the size of the scheduling problem, which affects the time/number of operations required to find a solution, or conversely, affects the efficiency of the solution that can be found in a given time.

E.1.2.1 Activity resolution - defining activities at a fine level of detail, e.g., to achieve more efficient resource utilization, increases the number of activities to be scheduled.

E.1.2.2 Flight system autonomy - flight systems with a low degree of automation require more commanding and conflict avoidance than more autonomous flight systems.

E.1.2.3 Number of instruments/parallel science - multiple instruments operating in parallel require the scheduling of more activities than are required for a single instrument operating at any given time.

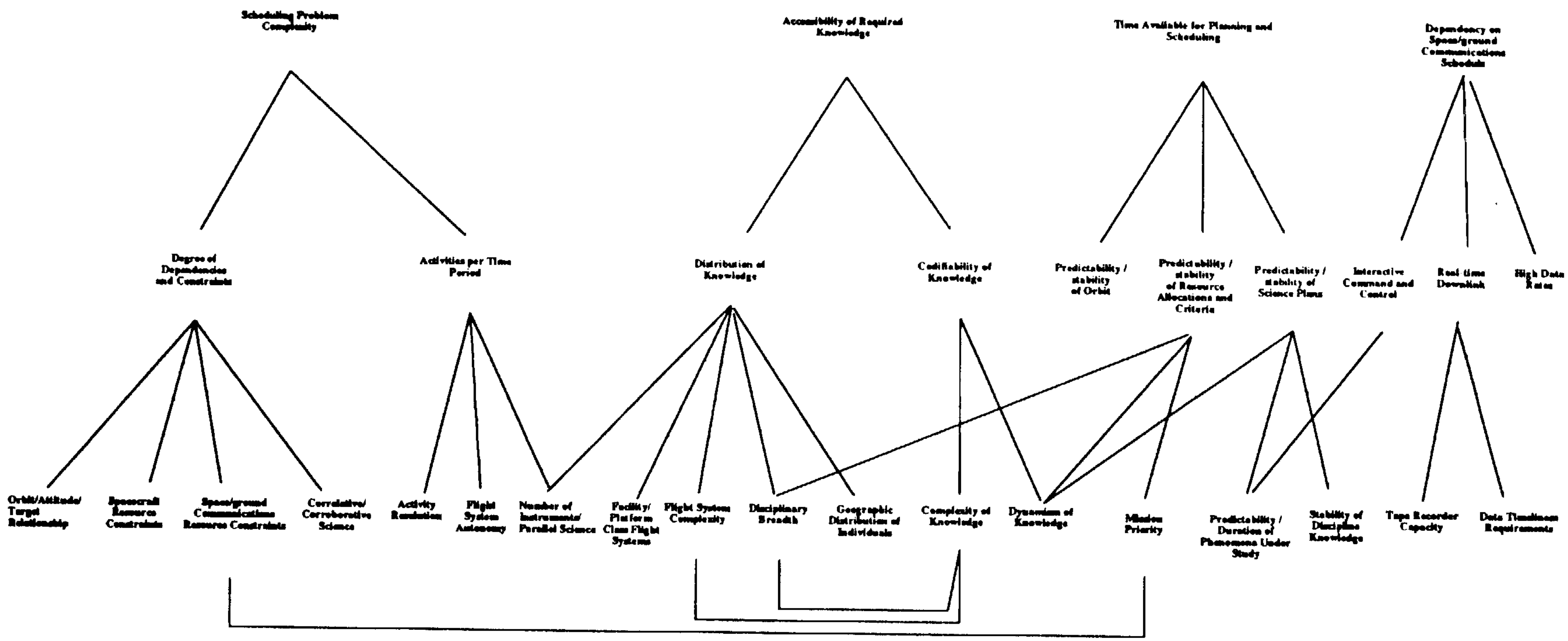

Figure E-1. The inherent difficulty of planning and scheduling a mission, independent of the capabilities of planning and scheduling systems, is a function of the inherent complexity of the problem, the accessibility of the required knowledge, the time available for planning and scheduling, and the mission's dependency on the space-to-ground communications schedule. These characteristics can be used to evaluate mission concepts in their earliest phases to identify potential operational difficulties.

E.2 **Accessibility of Required Knowledge** - the degree to which planning and scheduling is readily available when and where it is needed affects the speed with which plans and schedules can be formulated, and the level of communications between individuals and the system required to do so.

E.2.1 Distribution of knowledge - a high degree of distribution of planning and scheduling knowledge and information among individuals and locations means that more persons and locations must be involved in the planning and scheduling process, generally increasing the proportion of time that must be spent in communications.

E.2.1.1 Number of Instruments - more instruments generally means the involvement of more investigators, each with specialized knowledge that is difficult to transfer to others.

E.2.1.2 Facility/Platform-class Flight Systems - Flight systems intended for broad, multi-purpose use may involve a changing contingent of personnel with time.

E.2.1.3 Flight System Complexity - highly complex spacecraft and instruments generally requires the involvement of more engineers and analysts, because the amount of information involved exceeds the capacity of a small number of individuals.

E.2.1.4 Disciplinary Breadth - multi-disciplinary missions involve a broader range of knowledge than do missions which are dedicated to a single mission. This is especially evident in the difficulty of developing resource allocation criteria spanning multiple disciplines.

E.2.1.5 Geographic Distribution of Individuals - communications between individuals is facilitated by their colocation. Distributing them tends to increase the formal coordination load on planning and scheduling system capabilities.

E.2.2 Degree of codification of knowledge - the degree to which knowledge is codified as data makes it useable by systems as well as persons, and facilitates its interchange in time-critical situations.

E.2.2.1 Complexity of knowledge - the complexity of knowledge limits the extent to which it can be captured as data.

E.2.1.2 Dynamism of knowledge - the extent to which planning and scheduling knowledge is dynamic limits the extent to which it can be captured and processed as data, which limits its accessibility to the planning and scheduling system.

E.3 **Time Available for Planning and Scheduling** - the time available for fomulating and solving a problem is related to the predictability and stability of a mission's operational requirements and constraints.

E.3.1 Predictability/Stability of Orbit/attitude - high earth orbits are more predictable than low earth orbits, and thus allow ephemeral predictions to be made earlier, providing more lead time for planning and scheduling.

E.3.2 Predictability/Stability of Resource Allocations and Criteria - The more predictable and stable are resource allocations, the more time is available for finding a solution within those constraints. High-priority missions have the most predictable allocations, because there is a high likelihood that they will be allocated what they request. Highly stable resource allocations and criteria also enable them to be codified, supporting access to this information.

E.3.3 Predictability/Stability of Science Plans - Highly predictable phenomena and strategy, such as performing a mapping or survey mission, afford greater lead time for developing plans and schedules than highly unpredictable, short duration phenomena, such as targets of opportunity or those requiring interactive command and control (e.g., solar features).

E.4 **Dependency on space/ground communications schedule** - the degree to which a mission is dependent upon the space/ground communications schedule is the degree to which the mission's scheduling authority is distributed between it and the NCC. Distribution of scheduling authority increases the time required to find a satisfactory solution and the level of communications required to do so.

E.4.1 Interactive command and control - missions requiring interactive command and control are highly dependent on the space/ground communications schedule.

E.4.1.1 Unpredictable phenomena/strategy - missions studying unpredictable phenomena, such as dynamic solar features, may require interactive command and control, and thus are limited by uplink/downlink opportunities.

E.4.2 Real-time downlink - mission requiring real-time downlink are highly dependent on the space/ground communications schedule.

E.4.2.1 Tape recorder capacity - missions with minimal tape recorder capacity are unable to store significant amounts of data on board, thus limiting their data acquisition according to downlink opportunities.

E.4.2.2 Data Timeliness Requirements - missions whose data has a very short life expectancy, such as operational meteorological missions, must downlink the data shortly after it is acquired, thus limiting data acquisition according to downlink opportunities.

E.4.3 High Data Rates - missions requiring exceptionally high downlink communications rates are thereby contending for the more scarce, high-rate communications services.

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16. Abstract

The study was performed to:

- Document the lessons learned on planning and scheduling activities for a number of missions and institutional facilities in such a way that they can be applied to future missions
- Provide recommendations to both projects and Code 500 that will improve the end-to-end planning and scheduling process
- Identify what, if any, mission characteristics might be related to certain lessons learned

The results are a series of recommendations of both a managerial and technical nature related to underlying lessons learned.

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